Impact Analysis of Transportation Modal Shift on Regional Energy Consumption and Environmental Level: Focused on Electric Automobiles

Hong Bae Kim, Chang Ho Hur

***Abstract*—**Many governments have tried to reduce CO_2 emissions which are believed to be the main cause for global warming. The deployment of electric automobiles is regarded as an effective way to reduce CO_2 emissions. The Korean government has planned to deploy about 200,000 electric automobiles. The policy for the deployment of electric automobiles aims at not only decreasing gasoline consumption but also increasing electricity production. However, if an electricity consuming regions is not consistent with an electricity producing region, the policy generates environmental problems between regions. Hence, this paper has established the energy multi-region input-output model to specifically analyze the impacts of the deployment of electric automobiles on regional energy consumption and CO_2 emissions. Finally, the paper suggests policy directions regarding the deployment of electric automobiles.

***Keywords*—**Electric automobiles, CO_2 emissions, regional imbalances in electricity production and consumption, energy multi-region input-output model.

I. Introduction

THESE days, global warming has become one of the most serious issues around world, and many governments are making every effort to reduce CO_2 emissions which are believed to be the main culprit behind global warming. The Korean government, for example, has planned to specifically reduce 233.1 Mt CO_2 equivalent of greenhouse gas emissions to 30% below 1990 levels by 2020 [1]. In order to achieve this plan, the government has implemented various policies including the deployment of 200,000 electric automobiles by 2020 [2].

Many researchers have insisted that electric automobiles could be a useful way to reduce gasoline consumption and CO_2 emissions [3]-[6]. For instance, if 100 million electric automobiles are deployed, they will decrease CO_2 emissions by 30% [7]. This is because electric automobiles neither consume gasoline nor emit CO_2 when in use. However, the deployment of electric automobiles will lead to a decrease in gasoline consumption and an increase in electricity production at the same time. In the production process of electricity, CO_2 is emitted because various sources of energy including petroleum and coal are used. This implies that the policy for electric automobile deployment has two impacts on CO_2 emissions positively and negatively, while replacing gasoline vehicles. Specifically, if the electricity consumption of a region differs from its electricity production, the policy will generate another problems between regions. The Korea Energy Economics and Institute pointed out that there are only six electricity self-sufficient regions in Korea [8]. This means that the deployment of electric automobiles will increase regional imbalance involving electricity consumption and production. However, researchers have paid little attention to this discrepancy as well as consequence on the environment.

This paper attempts to analyze the impacts of the electric automobile deployment policy on regional energy consumption and CO_2 emissions. The paper is organized as follows: Section II presents an energy multi-region input-output model for the analysis. Section III describes employed data, and Section IV establishes two scenarios regarding regional electricity production, energy consumption, and CO_2 emissions and applies the model to the scenarios. Lastly, Section V includes a summary and policy directions.

II. The Model

A. The Energy Multi-Region Input-Output Model

Electricity is generated by using various energy sources, e.g., hydro, coal, oil, wind, etc. This implies that the amount of CO_2 emissions is determined according to the source of energy used to generate the electricity. Hence, in order to analyze the impacts of deploying electric automobiles on energy consumption and CO_2 emissions, energy sources should be specified in the model. The paper employs the energy multi-region input-output model. In the model, industrial sectors are largely divided into energy sectors and non-energy sectors. The commodity distribution of each sector is expressed in the matrix as:

$$\begin{bmatrix} X_e \\ X_{ne} \end{bmatrix} = \left\{ \begin{bmatrix} I & 0 \\ 0 & I \end{bmatrix} - \begin{bmatrix} A_{ee} & A_{en} \\ A_{ne} & A_{nn} \end{bmatrix} \right\}^{-1} \begin{bmatrix} F_e \\ F_{ne} \end{bmatrix} \tag{1}$$

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TABLE I
INDUSTRY STANDARD CLASSIFICATION 2013 CATEGORIZED BY ENERGY SECTORS AND UNITS OF OIL CONVERSION TONS OF ENERGY SECTORS

Numbers	Division	Basic Unit (TOE/Million won)
1	Hard coal	0.514
2	Coking coal	0.658
3	Crude oil	1.073
4	Natural gas	1.304
5	Cokes	0.696
6	Coal briquette	0.542
7	Naphtha	0.771
8	Gasoline	0.778
9	Jet fuel	0.873
10	Kerosene	0.879
11	Diesel fuel	0.901
12	Heavy oil	0.964
13	LPG	1.195
14	Solvent	0.795
15	Lubricant	0.950
16	Asphalt	0.991
17	Water power	0.211
18	Fire power	0.211
19	Nuclear power	0.211
20	Private power	0.211
21	Renewable energy	0.211
22	City gas	1.272
23	Steam, chilled or hot water	1.272

where, X_e: total output matrix of energy sectors ($mg\times 1$), X_{ne}: total output matrix of non-energy sectors ($mh\times 1$), A_{ee}: technical coefficients matrix of energy sectors ($mg\times mg$), A_{en}: technical coefficients matrix of energy and non-energy sectors ($mg\times mh$), A_{ne}: technical coefficients matrix of non-energy and energy sectors ($mh\times mg$), A_{nn}: technical coefficients matrix of non-energy sectors ($mh\times mh$), F_e: final demand matrix of energy sectors ($mg\times 1$), F_{ne}: final demand matrix of non-energy sectors ($mh\times 1$), g: number of energy sectors, h: number of non-energy sectors, m: number of regions, n: number of total industry sectors.

From (1), changes of the energy sectors' outputs are calculated by:

$$\Delta X = I_e(I-A^*)^{-1}\Delta F \tag{2}$$

where: ΔX: changes of energy sector's outputs ($mn\times 1$), A^*: hybrid technical coefficients ($mn\times mn$), I_e: diagonal matrix ($mn\times mn$), 1 for energy sectors and 0 for non-energy sectors, ΔF: changes in final demand of energy sectors due to the deployment of electric automobiles ($mn\times 1$) .

B. The Deployment of Electric Automobiles

A region is generally characterized by an open system. This implies that several commodities and factors to produce electricity are allowed to move across regions without institutional obstacles. The final demands of the energy sectors are expressed as:

$$\Delta F = \begin{pmatrix} \Delta F^1 \\ \vdots \\ \Delta F^r \\ \vdots \\ \Delta F^m \end{pmatrix}, \Delta F^r = \begin{pmatrix} \Delta F^r_{electricity} \\ -\Delta F^r_{electricity} \\ 0 \end{pmatrix} \tag{3}$$

C. The Energy Consumption and Its CO_2 Emissions

The CO_2 emissions are calculated by the amount of energy consumptions of the energy sectors. Before the analysis, variables and molecules are premised as:

$$\Delta CE^r_i = \Delta X^r_i \times cef_i \times (\frac{44}{12}) \tag{4}$$

where: ΔCE^r_i: changes of CO_2 emissions by energy sector i in region r, cef_i: carbon emission coefficients by energy sector i (C Ton/TOE), 44: molecular weight of carbon dioxide, 12: molecular weight of carbon.

$$\Delta CE^r_i = \Delta X^r_i \times cef_i \times (\frac{44}{12}) \tag{5}$$

where: $\Delta TCE^{r(n)}$: changes of CO_2 emissions in region(nation).

III. DATA

This section describes the data employed in this paper. The multi-region input-output table 2013 was constructed using the regional interindustry transaction table published by Bank of Korea [9]. Here, the industrial sectors were aggregated into 23 energy sectors and 28 non-energy sectors, as shown in Table I. The Korean economics consists of 16 regions. The monetary units of the energy sectors were converted into physical units as a ton of oil equivalent by suing the energy statistics published by the Korea Energy Economics and Institute [8] and the standard energy calories manual published by the Ministry of Trade, Industry and Energy [10]. Moreover, the electricity demand for electric automobiles was estimated by suing the annual driving distances of gasoline vehicles (DM) and the fuel efficiency per electric automobile (α). Those data were obtained from the Korea Transportation Safety Authority [11] and the Korea Energy Management Corporation [12]. The CO_2 emissions were calculated using the carbon emission coefficients of the Intergovernmental Panel Climate Change (IPCC) guideline provided by the Korea Energy Economics and Institute [13].

According to the data on the Korea Transportation Safety Authority [11], total number of registered gasoline vehicles was 9,317,930 in 2013. The gasoline consumption for the registered gasoline vehicles was estimated at 5,844,816.6 TOE, as shown in Table II. For example, the number of 4,372,185 gasoline vehicles registered in Seoul Metropolitan Area accounted for 45.7% of the total gasoline consumption. On the other hand, there were only 637,390 gasoline vehicles registered in Gwangju, Ulsan, and Jeju, and they needed for only 6.9%of the total gasoline consumption. It means that replacing gasoline vehicles by electric automobiles in the Seoul Metropolitan Area may decrease CO_2 emissions.

TABLE II
THE NUMBER OF GASOLINE VEHICLES AND GASOLINE CONSUMPTION IN 2013

Regions	Number of Gasoline Vehicles	Driving Distance per Day (km)	Annual Distance (million km)	Gasoline Consumption (TOE)
Seoul	1,632,507	26.8	15,969	920,298.1
Incheon	520,594	30.3	5,758	331,803.1
Gyeonggi	2,219,084	30.4	24,623	1,419,011.8
Daejeon	309,348	28.6	3,229	186,102.4
Chungbuk	296,284	30.7	3,320	191,331.0
Chungnam	388,853	32.0	4,542	261,742.4
Gwangju	260,547	30.2	2,872	165,512.8
Jeonbuk	319,881	31.4	3,666	211,279.2
Jeonnam	295,718	32.5	3,508	202,162.1
Daegu	528,094	29.3	5,648	325,474.9
Gyeongbuk	537,781	31.0	6,085	350,675.8
Busan	607,140	29.0	6,427	370,361.2
Ulsan	253,348	29.3	2,709	156,143.5
Gyeongnam	737,267	32.1	8,638	497,815.6
Gangwon	277,989	29.7	3,014	173,669.2
Jeju	133,495	29.0	1,413	81,433.2
Total	9,317,930	30.1	101,420	5,844,816.6

As mentioned previously, the deployment of electric automobiles will result in decreasing demand for gasoline and increasing demand for electricity. In general, electricity production is concentrated in some regions, including Incheon, Chungnam, Jeonnam, Gyeongbuk, Busan, and Gyeongnam. In Table III, those electricity producing regions accounted for 86.0% of the total electricity production in Korea.

TABLE III
THE ELECTRICITY PRODUCTION AND CONSUMPTION OF ELECTRICITY SELF-SUFFICIENT REGIONS IN 2013 (GWH)

Regions	Electricity Production [A]	Electricity Consumption [B]	Electricity Self-Sufficient Rate (%) [A/B]
Incheon	80,861	22,673	356.6
Chungnam	121,230	45,467	266.6
Jeonnam	67,705	30,302	223.4
Gyeongbuk	68,716	45,444	151.2
Busan	38,074	20,365	187.0
Gyeongnam	68,300	33,531	203.7
Total	444,886	197,782	224.9

IV. ANALYSIS

A. Scenario Description

Two scenarios are established as below. The purpose of each scenario is to analyze the impacts of the corresponding policy on regional energy consumption and CO_2 emissions.

- *Scenario #1*: a total of 200,000 electric automobiles increased nationally.
- *Scenario #2*: a total of 200,000 electric automobiles increase in the Seoul Metropolitan Area.

B. Analysis Results

The proportion of regional gasoline vehicles in the total registered gasoline vehicles is applied to the deployment of 200,000 electric automobiles. The impacts of electric automobile deployment policy on regional total energy consumption and CO_2 emissions are summarized, as shown in Tables IV, VI, and VII. It shows that the total CO_2 emissions increased by 270,887.0 tCO_2, nationally. More specifically, CO_2 emissions of the regions such as Chungnam, Seoul, and Ulsan decreases by 91,237.1 tCO_2, whereas CO_2 emissions of regions including Gyeonggi, Incheon, and Gyeongnam increases by 454,644.1 tCO_2. These results indicate that the amount of energy consumption to generate electricity is concentrated on some regions and has significant impacts on increasing CO_2 emissions.

Scenario #2 assumes that the 200.000 electric automobiles are deployed in the Seoul Metropolitan Area, including Seoul, Incheon, and Gyeonggi. Total CO_2 emissions increases by 966,764.9 tCO_2. In particular, CO_2 emissions of Gyeonggi and Incheon increases by 992,300.1 tCO_2, whereas CO_2 emissions of Seoul decreases by 71,808.5 tCO_2.

These results show that the deployment of electric automobiles intensifies the imbalance in CO_2 emissions between electricity consumption regions and electricity production regions. It turns out that the deployment of electric automobiles is ineffective to reduce CO_2 Emissions in Korea.

TABLE IV
CHANGES IN ENERGY CONSUMPTIONS AND CO_2 EMISSIONS BY SCENARIOS

SCENARIO #1			SCENARIO #2		
Region	ΔEnergy Consumption (TOE)	ΔCO_2 Emissions (tCO_2)	Region	ΔEnergy Consumption (TOE)	ΔCO_2 Emissions (tCO_2)
Total	174,490.0	270,887.0	Total	443,451.5	966,764.9

If raising the electricity production rate of new and renewable energy by 10% to all regions at the level of average of the 35 OECD countries, the restructuring policy of the electricity production system will decrease CO_2 emissions by 24,516.2 tCO_2, as shown in Table V.

TABLE V
CHANGES IN ENERGY CONSUMPTIONS AND CO_2 EMISSIONS BY SCENARIOS

SCENARIO #1	
Division	ΔCO_2 Emissions (tCO_2)
Restructuring Policy	-24,516.2

V. CONCLUSION

This paper has investigated the impacts of the deployment of electric automobiles on the energy consumption and the CO_2 emissions by constructing an energy multi-region input-output model. The industrial sectors in the energy multi-region input-output model are specifically categorized into energy sectors and non-energy sectors. This can be helpful in specifying how much energy inputs are needed to generate electricity in inter-industry activities. The energy multi-region input-output model was applied to three policy scenarios involving the deployment of electric automobiles. The scenario analysis seeks to evaluate the regional impacts of the electric automobile deployment policy on regional energy consumption and the CO_2 emissions. There are important policy implications. The deployment of electric automobiles will rather increase CO_2 emissions in Korea, but the impacts of the policy reveals differently among regions. Moreover, deploying electric automobiles in Seoul Metropolitan Area is found to be less efficient to decrease the CO_2 emissions. The restructuring electricity production system is requested to reduce the CO_2 emissions by using new and renewable energy to implement the electric automobiles.

APPENDIX

TABLE VI
CHANGES IN ENERGY CONSUMPTIONS AND CO_2 EMISSIONS BY SCENARIOS #1

Number	ΔEnergy Consumption (TOE)	$\Delta C0_2$ Emissions (tCO_2)
Seoul	-5,868.8	-33,775.6
Incheon	83,112.8	186,782.6
Gyeonggi	109,742.0	225,464.3
Daejeon	-1,174.0	-6,791.2
Chungbuk	-1,363.5	-7,402.3
Chungnam	-10,663.1	-36,357.3
Gwangju	-1,161.2	-6,322.4
Jeonbuk	-1,423.3	-7,942.1
Jeonnam	-4,650.3	-16,807.1
Daegu	-2,059.9	-11,897.6
Gyeongbuk	-2,170.5	-12,770.7
Busan	-2,353.5	-13,638.4
Ulsan	-6,866.4	-21,104.2
Gyeongnam	22,832.4	42,397.2
Gangwon	-921.1	-5,963.5
Jeju	-521.7	-2,984.7
Total	174,490.0	270,887.0

TABLE VII
CHANGES IN ENERGY CONSUMPTIONS AND CO_2 EMISSIONS BY SCENARIOS #2

Number	ΔEnergy Consumption (TOE)	$\Delta C0_2$ Emissions (tCO_2)
Seoul	29.0	75.3
Incheon	99,596.8	222,834.6
Gyeonggi	13,047.7	30,507.5
Daejeon	9.1	23.0
Chungbuk	29.5	69.0
Chungnam	15,580.5	29,991.6
Gwangju	6.5	16.5
Jeonbuk	57.5	121.2
Jeonnam	16,193.4	35,400.3
Daegu	17.5	46.1
Gyeongbuk	16,811.5	28,498.4
Busan	17,297.4	28,790.0
Ulsan	7,522.6	22,076.8
Gyeongnam	41,224.7	80,628.9
Gangwon	51.4	137.3
Jeju	19.6	33.4
Total	227,494.7	479,250.0

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